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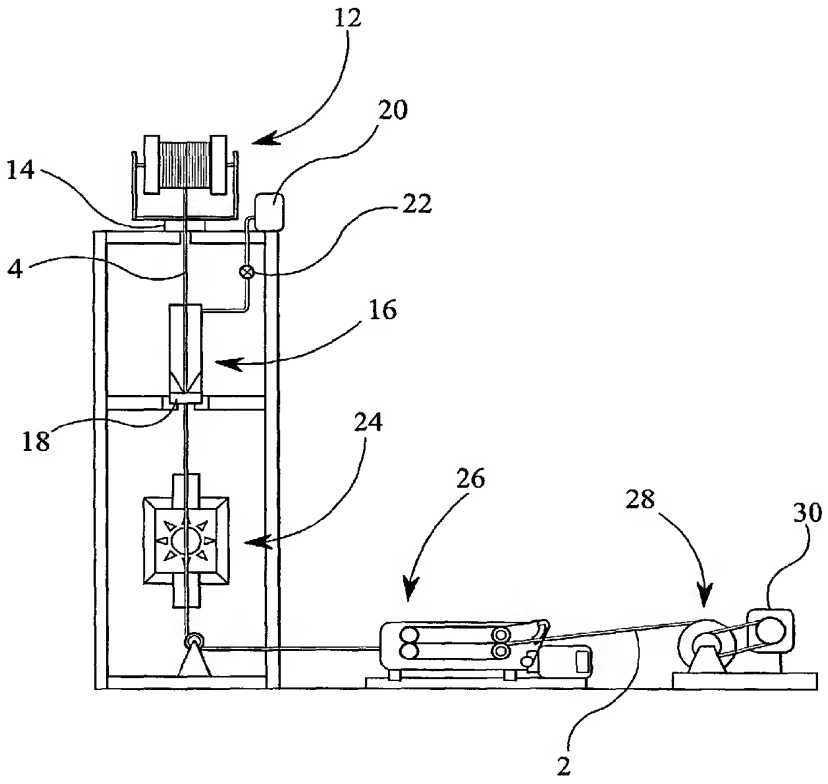

(57) Abstract: A flexible high strength composite comprises at least one carbon fibre tow (4), comprising filaments of carbon fibre material, impregnated in a flexible polymeric matrix (6). The composite is made by passing the at least one tow through a tank (16) of impregnating material. Twisting means (12, 14) is provided for twisting the at least one tow (4) as it passes through the impregnating material in the tank (16). The impregnated tow is then cured in curing means (24) so as to cure the impregnating material applied to the tow (4) to form the flexible polymeric matrix (6).

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METHOD AND APPARATUS FOR MANUFACTURING A FLEXIBLE HIGH STRENGTH COMPOSITE

This invention concerns a method and an apparatus for manufacturing a flexible high strength composite which is suitable for use, for example, in structural applications, or as a line or tape such as for measuring, marking or surveying equipment.

According to one aspect of the present invention there is provided a method of manufacturing a flexible high strength composite comprising at least one carbon fibre tow, comprising filaments of carbon fibre material, impregnated in a flexible polymeric matrix, the method comprising the steps of:

passing the at least one tow through a tank of impregnating material;

twisting the at least one tow as it passes through the impregnating material; and

curing the impregnating material applied to the at least one tow to form the flexible polymeric matrix.

According to another aspect of the present invention there is provided an apparatus for manufacturing a flexible high strength composite comprising at least one carbon fibre tow, comprising filaments of carbon fibre material, impregnated in a flexible polymeric matrix, the apparatus comprising:

means for supplying at least one tow;

a tank for impregnating material;

means for twisting the at least one tow as it passes through the tank; and

curing means for curing the impregnating material applied to the at least one tow to form the flexible polymeric matrix.

The twisted tow may have up to about 150 or more twists per metre.

The at least one tow may be passed downwardly through the tank of impregnating material, the at least one tow exiting the tank through an aperture at a lower end of the tank.

Means may be provided to maintain the level of impregnating material in the tank substantially at a predetermined level.

The impregnating material may incorporate a diluent to reduce the viscosity thereof.

The impregnating material may comprise a prepolymeric material. The prepolymeric material may be polymerisable with a UV initiator or with a thermal initiator.

The impregnated tow may be passed downwardly through a curing means.

Means may be provided downstream of the curing means for controlling the speed of the tow through the tank and through the curing means.

Means may be provided to accumulate the flexible composite.

The flexible composite may be used, for example, in structural applications or as a line or tape such as for measuring, marking or surveying equipment, or as a high strength flexible conductor.

For a better understanding of the invention and to show more clearly how it may be carried into effect, reference will now be made, by way of example, to the accompanying drawings in which:

Figure 1 is a perspective view of an embodiment of a flexible high strength composite made in accordance with the present invention; and

Figure 2 is a schematic illustration of an apparatus according to the present invention for manufacturing a flexible high strength composite.

Referring first to the Figure 1, a flexible high strength composite 2 comprises at least one carbon fibre tow 4, comprising filaments of carbon fibre material, encapsulated in a flexible polymeric matrix 6.

As shown, a plurality of carbon fibre tows 4 are provided, which may be of straight (i.e. unidirectional) form, or of twisted form, and which may each be of circular or rectangular cross-section.

Each of the carbon fibre tows 4 comprises filaments of carbon fibre material which suitably comprises a turbostratic structure of carbon which may be formed from one or more precursors such as mesophase pitch or polyacrylonitrile polymer.

As many as one thousand tows 4 may be provided in the composite 2. One or more of the tows 4 may incorporate filaments of an alternative material to provide specific properties to the resulting composite. For example, optical fibres may be incorporated so that optical signals may be sent along the composite.

Each tow 4 suitably comprises from 50 to 12000 filaments of carbon fibre material, each having a diameter of between 0.05 and 20 microns and suitably of about 7 microns.

If the tows 4 are of twisted form, up to about 150 twists per metre may be provided. In a typical twisted form of construction, about 100 twists per metre are provided.

If the tows are of braided form, such braided form may be arranged such that some of the tows 4 are interwoven in braided form around one or more central tows, that is, in the form of maypole braiding. Alternatively, the tows 4 may be braided in situ.

The flexible polymeric matrix 6 comprises a material which preferably wets the carbon fibre filaments of the tows 4 and preferably encapsulates each individual filament of the tows 4.

The flexible polymeric matrix 6 is arranged to adhere to the carbon fibre filaments of the tows 4. Such adhesion may be by means of an adhesive material, but is suitably by means of chemical bonding between material of the flexible polymeric matrix 6 and the carbon fibre filaments of the tows 4.

A substantially uniform distribution of the carbon fibre filaments of the tows 4 is preferably provided within the flexible polymeric matrix 6.

The flexible polymeric matrix 6 suitably comprises an elastomer, or a thermoplastic plastics material, or a thermosetting plastics material.

A suitable elastomer comprises polyurethane or silicone rubber.

A suitable thermoplastic plastics material comprises methacrylate, or trimethylolpropane triacrylate, or ethoxyethoxyethyl acrylate, or polyvinylchloride. Flexibilised derivatives of thermoplastic plastics materials may also be used.

A suitable thermosetting plastics comprises vinyl ester, a flexible derivative of a polyester resin, or flexibilised epoxy material.

The flexible polymeric matrix 6 may be applied as a prepolymeric resin material which impregnates the tow 4 and is subsequently polymerised, such as by heating or by means of applied radiation, such as ultra-violet radiation.

The resulting flexible composite 2 exhibits high tensile strength and high axial stiffness. It is also light in weight and exhibits high flexibility, having a low bend radius: that is, the flexible composite can be distorted repeatedly without failure of the composite. It also exhibits low thermal expansion.

In a particular example, a composite 2 is in the form of a line incorporating tows 4 with six thousand filaments and with a loading of carbon fibre to polymeric matrix 6 of about 80 percent. Such composite has an overall cross sectional area of about 2.9×10^{-7} square metres, a tensile strength of about 3 to 4 GPa and an axial stiffness of about 300 GPa. The composite has a bend diameter of about 10mm where there is one twist in the tow every 30mm.

The flexible composite 2 may be used in structural applications, but finds particular application as a line or tape for measuring, marking or surveying equipment.

One or more layers 8 of a flexible covering material, such as a polymer material may be provided on the composite 2. Such one or more layers 8 may provide protection for the composite 2 or may incorporate markings or measurement data for use when the composite 2 is applied as a line or tape for measuring, marking or surveying equipment.

Where the tow or tows 4 are braided or are otherwise laid in a generally planar (sheet-like) arrangement the resulting composite will have a generally rectangular cross-section, that is it will be in the form of a tape or a sheet.

The flexible composite 2 is manufactured with the aid of an apparatus as shown in Figure 2 using a continuous pultrusion process.

A carbon fibre tow 4 is unwound as required from a reel 12, the reel being mounted on a base 14 which is rotatable about an upright axis to enable a twist to be

imparted to the tow 4 as it is unwound. By way of example, the tow 4 may be in the form of a high modulus 6K unidirectional tow.

The twisted tow 4 is aligned by way of an aperture in a supporting framework for the apparatus and passes downwardly through a resin tank 16 in which the tow continues to twist and which is provided with an aperture in the form of a coating die 18 at the lower end thereof. The coating die has a diameter of about 0.75 mm.

The resin tank 16 is initially filled with UV curable prepolymeric material to a predetermined level and the predetermined level is maintained by supplying further prepolymeric material from a storage tank 20 by means of a metering pump 22.

The tow, impregnated with the prepolymeric material, then passes downwardly into a curing means in the form of a UV curing oven 24 where the prepolymeric material is cured to form the desired flexible composite 2. The speed at which the tow is drawn through the resin tank 16, coating die 18 and curing oven 24 is determined by speed control means in the form of a speed-controlled hauler 26 through which the composite 2 passes. The speed of the hauler 26 can be controlled to ensure the tow 4 is fully coated and impregnated with the prepolymeric material and to ensure the curing time in the oven 24 is sufficient, but not excessive.

Finally, the flexible composite is wound (accumulated) on a reel 28 by means of a suitable drive 30. In this respect, we have found the use of a separate drive 30 to be significant in enabling constant speed of the tow

through the resin tank 16, coating die 18 and curing oven 24 to be maintained.

When a flexible composite 2 was made with an untwisted tow and a flexible resin, it was found that when bent in flexural mode the composite buckled and kinked at bend radii about five times higher than the radius of the composite 2. Kinking also gave rise to separation of filaments of the tow such that the composite was permanently damaged. In use, the reel was rotated so as to impart either 88-90 turns per metre or 45-47 turns per metre, although other degrees of twist may be employed, for example up to 150 or more turns per metre. In each case the bend radius was reduced and the tendency to kink was reduced, although the composite with the greater number of twists was found to be more flexible and to have better shape retention. This is because twisting makes a bundle of fibres more flexible in that it allows the individual filaments in the bundle to move and displace more readily and to distribute the predominantly shear loads in the composite.

In addition, the nature of the flexible polymeric matrix 6 was found to be important. The difficulty in achieving a small bend radius and low bend stiffness are related to the flexibility of the polymeric matrix. A prepolymeric material, for example of a type used in the manufacture of optical fibres, was found to be preferable to thermoplastic or thermosetting plastics materials. Suitable prepolymeric materials include multifunctional urethane/acrylic resin materials which may contain trimethylolpropane triacrylate and ethoxyethoxyethyl acrylate. Although prepolymeric materials can be polymerised using thermal or UV initiators, UV initiators were considered to be preferable due to a wider

processing window and more rapid curing. It was also advantageous to dilute the prepolymeric material with a suitable diluent, such as HEMA (2hydroxyethylmethacrylate - $CH_2C(CH_3)COOHCH_2CH_2OH$) to reduce the viscosity of the prepolymeric material in order to increase the rate at which the tow can be impregnated.

We have found the continuous twisting of the tow as it passes through the resin tank 16 significantly improves impregnation of the prepolymeric material into the tow. The twisting of the fibres of the tow draws the prepolymeric resin material into the bundle of fibres, thereby allowing the individual fibres to be coated before the tow is tightened into a twisted configuration.

CLAIMS

1. A method of manufacturing a flexible high strength composite comprising at least one carbon fibre tow (4), comprising filaments of carbon fibre material, impregnated in a flexible polymeric matrix (6) characterised by the steps of:

passing the at least one tow (4) through a tank (16) of impregnating material;

twisting the at least one tow as it passes through the impregnating material; and

curing the impregnating material applied to the at least one tow to form the flexible polymeric matrix (6).

2. A method according to claim 1, characterised in that up to about 150 or more twists per metre are provided.

3. A method according to claim 1 or 2, characterised in that the at least one tow is passed downwardly through the tank (16) of impregnating material, the at least one impregnated tow exiting the tank through an aperture at a lower end thereof

4. A method according to claim 1, 2 or 3, characterised in that means (20, 22) is provided to maintain the level of impregnating material in the tank (16) substantially at a predetermined level.

5. A method according to any preceding claim, characterised in that the impregnating material incorporates a diluent to reduce the viscosity thereof.

6. A method according to any preceding claim, characterised in that the impregnating material comprises a prepolymeric material.

7. A method according to claim 6, characterised in that the prepolymeric material is polymerisable with a UV initiator.

8. A method according to claim 6, characterised in that the prepolymeric material is polymerisable with a thermal initiator.

9. A method according to any preceding claim, characterised by the step of passing the impregnated tow downwardly through a curing means (24).

10. A method according to any preceding claim, characterised in that means (26) is provided downstream of the curing means (24) for controlling the speed of the tow (4) through the tank (16) and through the curing means.

11. A method according to any preceding claim, characterised in that means (28, 30) is provided to accumulate the flexible composite (2).

12. Apparatus for manufacturing a flexible high strength composite comprising at least one carbon fibre tow (4), comprising filaments of carbon fibre material, impregnated in a flexible polymeric matrix (6) characterised by:

means for supplying at least one tow (4);

a tank (16) for impregnating material;

means (12, 14) for twisting the at least one tow (4) as it passes through the tank (16); and

curing means (24) for curing the impregnating material applied to the at least one tow (4) to form the flexible polymeric matrix (6).

13. An apparatus as claimed in claim 12, characterised in that the twisting means (12, 14) is adapted to apply up to about 150 or more twists per metre to the tow (4).

14. An apparatus as claimed in claim 12 or 13, characterised in that the tank (16) has an upper inlet and a lower outlet for the at least one tow (4) such that the tow passes downwardly through the tank thereby becoming impregnated with the impregnating material.

15. An apparatus as claimed in claim 12, 13 or 14, characterised in that means (20, 22) is provided to maintain the level of impregnating material in the tank (16) substantially at a predetermined level.

16. An apparatus as claimed in any one of claims 12 to 15, characterised in that the impregnating material incorporates a diluent to reduce the viscosity thereof.

17. An apparatus as claimed in any one of claims 12 to 16, characterised in that the impregnating material comprises a prepolymeric material.

18. An apparatus as claimed in claim 17, characterised in that the prepolymeric material is polymerisable with a UV initiator.

19. An apparatus as claimed in claim 17, characterised in that the prepolymeric material is polymerisable with a thermal initiator.

20. An apparatus as claimed in any one of claims 12 to 19, characterised in that means is provided for passing the impregnated tow downwardly through a curing means (24).

21. An apparatus as claimed in any one of claims 12 to 20, characterised in that means (26) is provided downstream of the curing means (24) for controlling the speed of the tow (4) through the tank (16) and through the curing means.

22. An apparatus as claimed in any one of claims 12 to 21, characterised in that means (28, 30) is provided to accumulate the flexible composite (2).

FIG 1

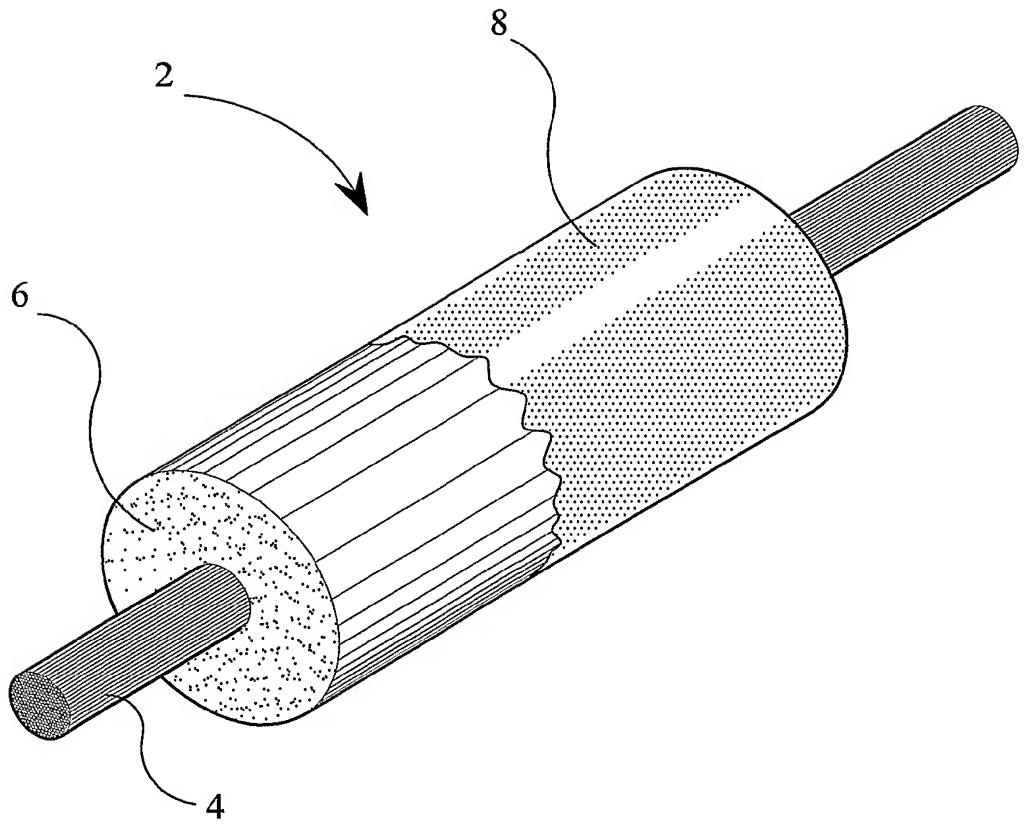
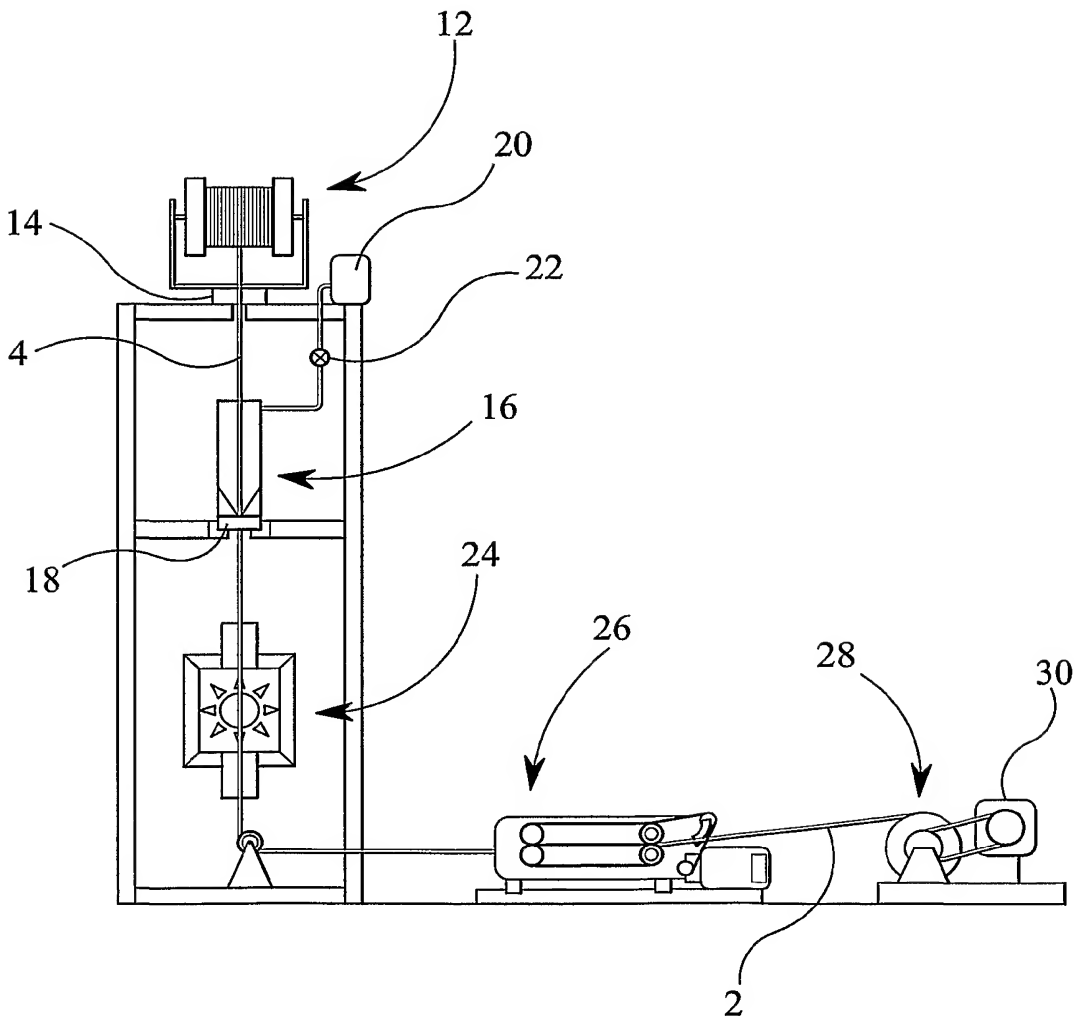


FIG 2



INTERNATIONAL SEARCH REPORT

PCT/GB 02/01950

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 B29B15/12

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 B29B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 853 021 A (FEDEROWSKY ROBERT ET AL) 1 August 1989 (1989-08-01) column 2, line 39 - line 43 column 3, line 1 - line 48 column 4, line 1 - line 4 column 4, line 28 - line 42 ---	1,3, 6-12,14, 17-22
X	US 5 639 307 A (BELLEMARE DAVID J) 17 June 1997 (1997-06-17) column 4, line 7 - line 10 column 4, line 34 - line 38 column 4, line 42 - line 45 column 4, line 47 - line 48 column 4, line 61 - line 65 column 5, line 24 - line 27 column 5, line 42 --- -/--	1,12

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
24 June 2002	04/07/2002

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Attalla, G

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INTERNATIONAL SEARCH REPORT

PCT/GB 02/01950

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
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